Properties of Real and "Virtual" Blends of FT IPK and JP-8

Reference:
Muzzell, P.; Stavinoha, L.; Freerks, R.; McKay, B.; Terry, A.; Sattler, E. "Properties of Fischer-Tropsch (FT) Blends for Use in Military Equipment", SAE Paper No. 2006-01-1702, April 2006.

2006 CRC Aviation Committee Annual Meeting

May 2, 2006

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
02 MAY 2006	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Properties of Real and Virtual Virtual Blends of FT IPK and JP JP-8	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
P. Muzzell; L. Stavinoha; R. Freerks; B. McKay; A. Terry; E. Sattler	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA	**15756RC**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	TACOM/TARDEC
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)
	15756RC

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

Presented at the CRC Aviation Committee Annual Meeting May 2, 2006, The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**31**	

Presentation Content

- Single Fuel on the Battlefield Policy
- OSD Assured Fuels Initiative (formerly OSD Clean Fuels Initiative)
  - Joint Battlespace Use Fuel of the Future (JBUFF)
- Near-term use of Fischer-Tropsch (FT) fuel
- Properties of JP-8 and FT IPK
- Properties of blends of FT IPK and JP-8
- Conclusions / Recommended Follow-on Study

Single Fuel on the Battlefield Policy

- JP-8 / JP-5 / Jet A-1(+CI/LI) is the single fuel for all tactical equipment (land, air, marine fleets)
  - Utilized in training and combat operation; CONUS and OCONUS
  - “Ready at a moment’s notice!”
  - Improved reliability and readiness
  - Reduced maintenance
- Currently, fuel is produced from crude oil (petroleum)
- Over 70% of fuel consumed by DoD is JP-8 / JP-5 / Jet A-1

OSD Assured Fuels Initiative

- Vision: DoD intends to catalyze commercial industry to produce clean fuels for the military from secure domestic resources using environmentally sensitive processes as a bridge to the future.

- Initiative aims to reduce/offset:
  - Growing dependence of the U.S. on foreign oil
  - Vulnerability of the mega-refineries supply
  - Divergence in the sulfur content of jet fuel and diesel fuel
  - Potential limits on operations due to emission regulations
  - Rising cost of fuel

Properties of FT IPK

- FT IPK can be refined to meet the JP-8 specification Table I values with exception of density
  - FT IPK included in this study is S-8 made by Syntroleum Corp.

- Properties of S-8
  - Density of 0.751-0.754 kg/L [ASTM D 4052]
    - Data for S-8 used in this study as reported by Syntroleum Corp.
    - JP-8 specification range of 0.775 – 0.840 kg/L
  - Negligible aromatics and sulfur content
    - JP-8 specification mandates maximum contents only
  - Cetane index of 67-70 [ASTM D 976*]
    - Data for S-8 used in this study as calculated by Army TARDEC
    - Cetane number >55 [ASTM D 613*]
      - S-8 data reported by Southwest Research Institute

* Test methods are not validated for Fischer-Tropsch fuels.

Technical Challenge

- Ensure that FT fuel can be used interchangeably with petroleum JP-8/JP-5/Jet A-1 fuel in use today
- FT Iso-Paraffinic Kerosene (IPK) contains no/low aromatic content
  - Some fuel-wetted elastomers sensitive to aromatic compounds (most notably nitrile) found in fuel distribution systems (e.g., o-rings)
  - Sensitive elastomers are known to swell when exposed to aromatic content in petroleum-derived fuels such as JP-8/JP-5/Jet A-1
  - When exposed to FT IPK, these sensitive elastomers may then shrink, creating risk of fuel leakage
    - Risk of fuel leakage is greatest for aged elastomer components that have taken on some compression set

Near-term use of FT Fuel

- Mitigate risk of introducing FT fuels to military fleet by blending FT fuels with petroleum derived fuels
- DEF STAN 91-91 approves the use of a blend of FT kerosene, produced by Sasol, with Jet A-1 for use at Johannesburg International Airport with two limitations:
    1. Final blend must have a minimum 8 vol. % aromatic concentration supplied by JP-8
    2. Final blend must contain less than 50% FT kerosene and have density >0.775 kg/L
- In near-term, FT fuel supply availability realistically only supports wide-use implementation of FT/petroleum fuel blends
    - Furthermore, most realistic scenario supports use of FT/petroleum fuel blends nearest manufacturing sites of FT IPK

Properties of JP-8

- Petroleum Quality Information System (PQIS)
  - Very useful database maintained by Defense Energy Support Center (DESC)
  - Contains critical chemical/physical properties for all bulk fuels procured
- PQIS data can be used to define a “property box” for JP-8 procured by region in CONUS (U.S.) and/or in OCONUS (worldwide)
- For the purposes of this study, 2004 CONUS data was used to develop the property ‘box’ for CONUS JP-8 fuel

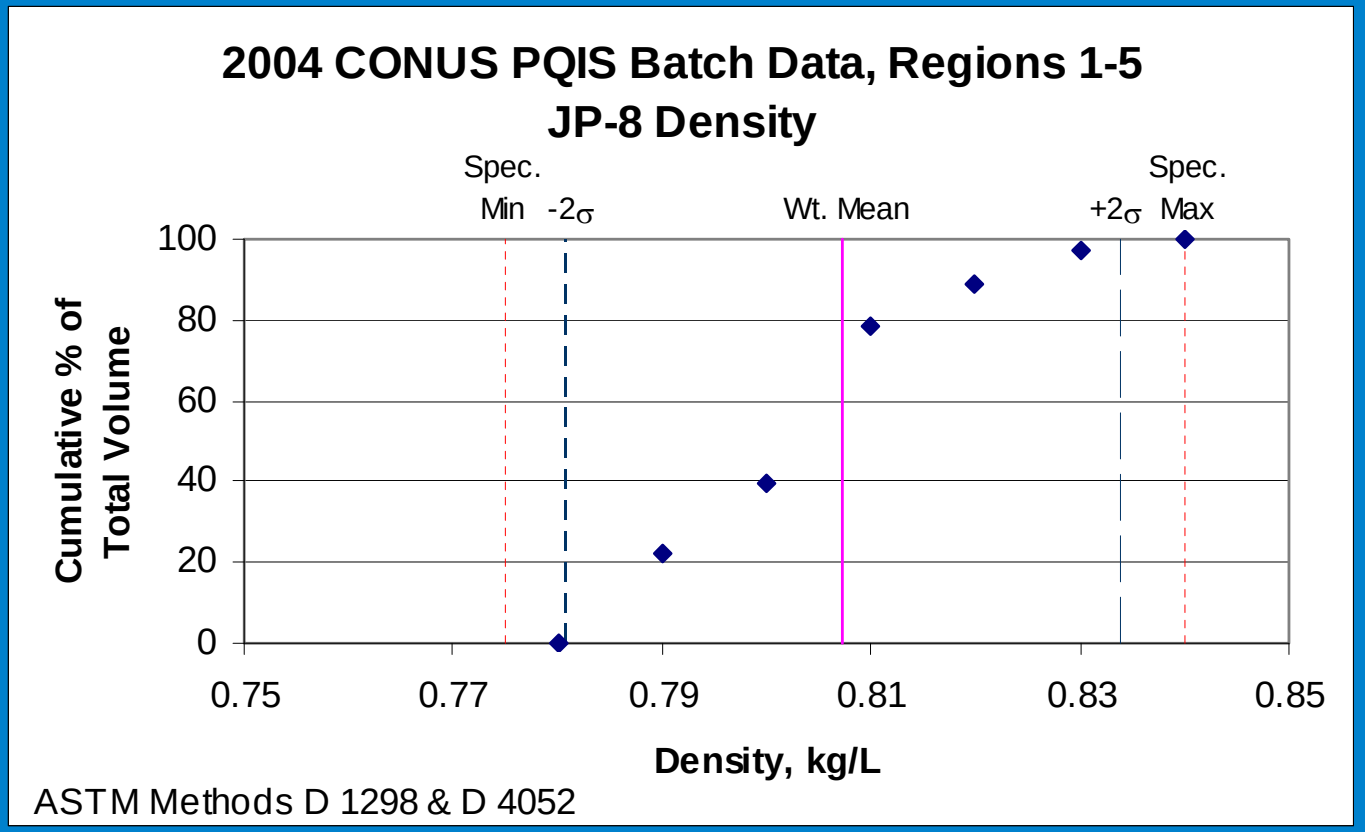
Analysis of PQIS JP-8 Data

- Analysis included 16,000+ JP-8 data points from 2061 batches associated with 2,004,941,934 gallons of JP-8 fuel (2004 only, CONUS Regions 1-5 only)
- Mean, weighted mean, +/- 2 sigma standard deviations, were calculated for several properties according to:
  - Fraction of regional and total CONUS volumes
  - Cumulative fraction of regional and total CONUS volumes
- Data included in analysis*
  - Density
  - Aromatic Content
  - Sulfur Content
  - Viscosity at -20 °C
  - Freeze Point
  - Final Boiling Point
  - Net Heat of Combustion
  - Cetane Index

*only a portion of the results from data analysis are presented in the SAE Paper

JP-8 Density

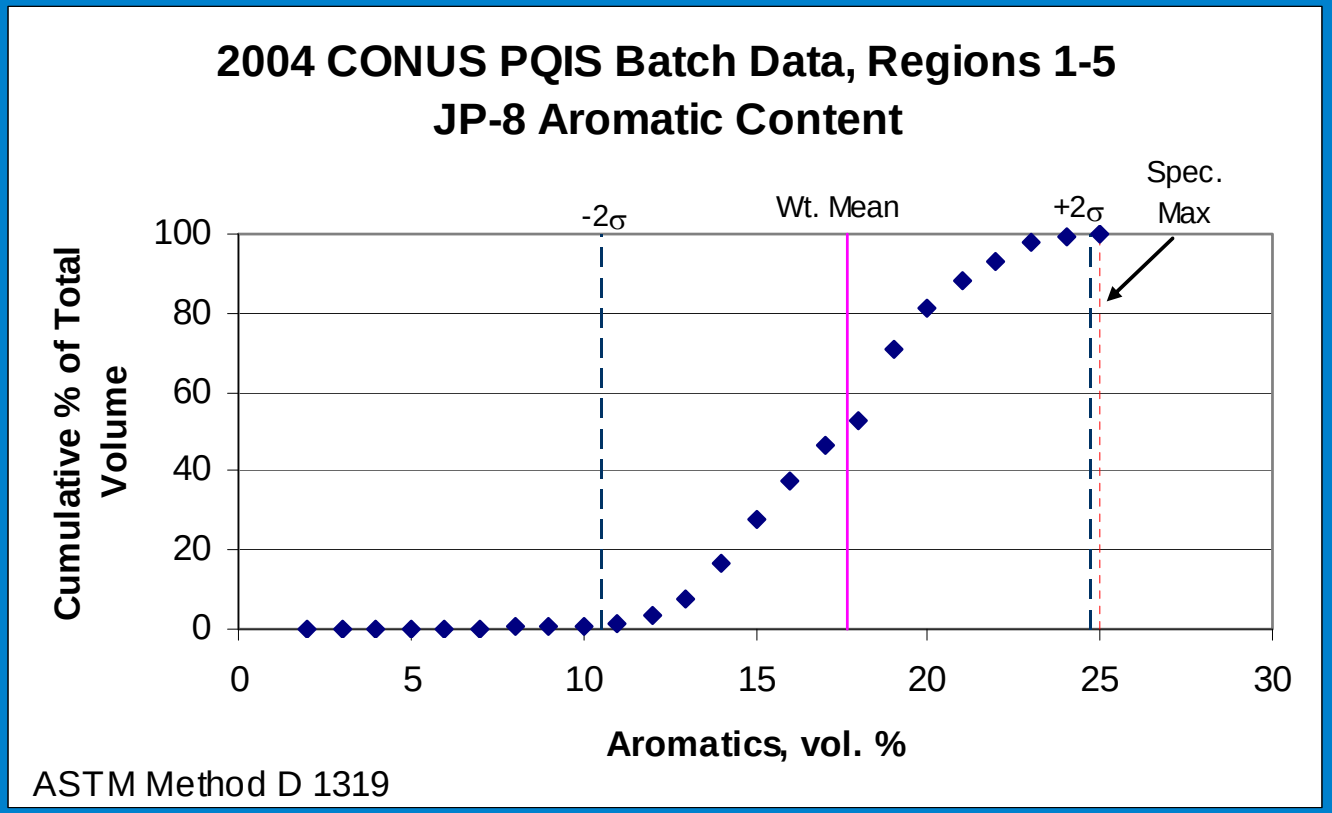
- JP-8 density ranged from 0.791 to 0.839 kg/L
- Weighted mean density is 0.807 kg/L



ASTM Methods D 1298 & D 4052

JP-8 Aromatic Content

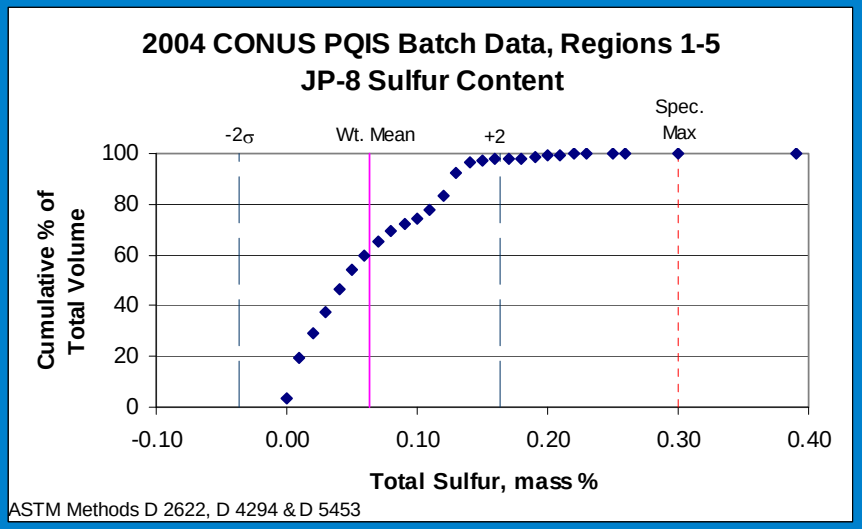
- JP-8 Aromatic content ranged from 1.8 to 25.0 vol. %
- Weighted mean aromatic content is 17.7 vol. %



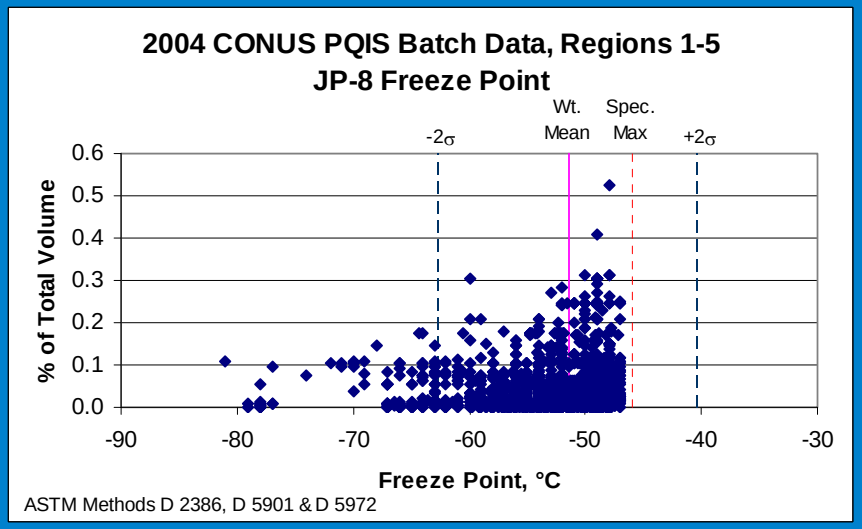
ASTM Method D 1319

JP-8 Fuel Properties

- Weighted mean sulfur content is 0.06 mass %
- Weighted mean freeze point is -51.5 °C
- Weighted mean viscosity at -20 °C is 4.7 mm^2/s
- Weighted mean cetane index is 43.9



ASTM Methods D 2622, D 4294 & D 5453



ASTM Methods D 2386, D 5901 & D 5972

Organizing JP-8 Data to Create "Virtual" Blends

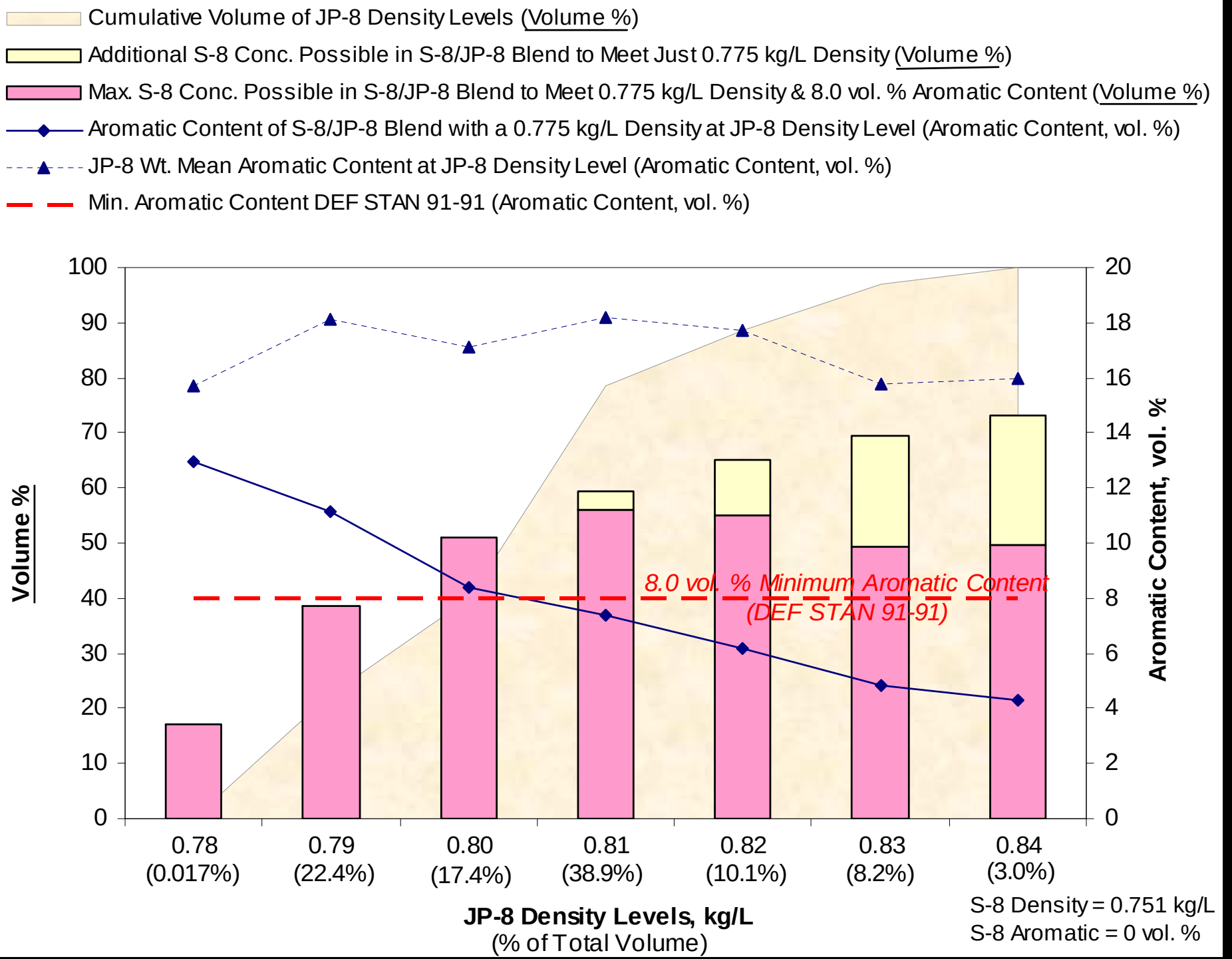
- JP-8 2004 PQIS was organized according to two properties:
  - Density; range of 0.791 to 0.839 kg/L
  - Aromatic content; range of 1.8 to 25.0 vol. %
- Density and Aromatic values were rounded-off to create "Levels"
  - Density Levels = 0.79, 0.80…. 0.83, 0.84 kg/L
  - Aromatic Levels = 2.0, 3.0…. 24.0, 25.0 vol. %
- At each Density Level, the weighted mean aromatic content was calculated, also the average sulfur content and average cetane index
- At each Aromatic Level, the weighted mean density was calculated, also the average sulfur content and average cetane index
- At each Level, the percentage of total volume of JP-8 procured was calculated to quantify overall exposure of military fleet to fuel with the property values at that Level
- "Virtual" blends were developed and associated properties predicted based on mathematical calculations

Creating "Virtual" Blends Based on Meeting Minimum Density

- Assume an S-8 density of 0.751 kg/L
- At each Density Level, calculated the maximum concentration of S-8 that can be blended in total volume (at that Density Level) to reach the minimum density allowable per JP-8 specification (0.775 kg/L)
- For example, at the JP-8 Density Level = 0.80 kg/L the calculation determines that 51 vol. % of S-8 can be blended to the JP-8 to reach min. density of 0.775 kg/L

$$51\ vol.\% = \left(1 - \frac{(0.775 - 0.751)\ kg/L}{(0.80 - 0.751)\ kg/L}\right) * 100$$

- S-8/JP-8 blend contains 51 vol. % of S-8 and 49 vol. % of JP-8


Cumulative Volume of JP-8 Density Levels (Volume %)
Additional S-8 Conc. Possible in S-8/JP-8 Blend to Meet Just 0.775 kg/L Density (Volume %)
Max. S-8 Conc. Possible in S-8/JP-8 Blend to Meet 0.775 kg/L Density & 8.0 vol. % Aromatic Content (Volume %)
Aromatic Content of S-8/JP-8 Blend with a 0.775 kg/L Density at JP-8 Density Level (Aromatic Content, vol. %)
JP-8 Wt. Mean Aromatic Content at JP-8 Density Level (Aromatic Content, vol. %)
Min. Aromatic Content DEF STAN 91-91 (Aromatic Content, vol. %)
Volume %
Aromatic Content, vol. %
100
90
80
70
60
50
40
30
20
10
0
20
18
16
14
12
10
8
6
4
2
0
8.0 vol. % Minimum Aromatic Content
(DEF STAN 91-91)
0.78
(0.017%)
0.79
(22.4%)
0.80
(17.4%)
0.81
(38.9%)
0.82
(10.1%)
0.83
(8.2%)
0.84
(3.0%)
JP-8 Density Levels, kg/L
(% of Total Volume)
S-8 Density = 0.751 kg/L
S-8 Aromatic = 0 vol. %

Key Takeaways from JP-8 Density Level Slide

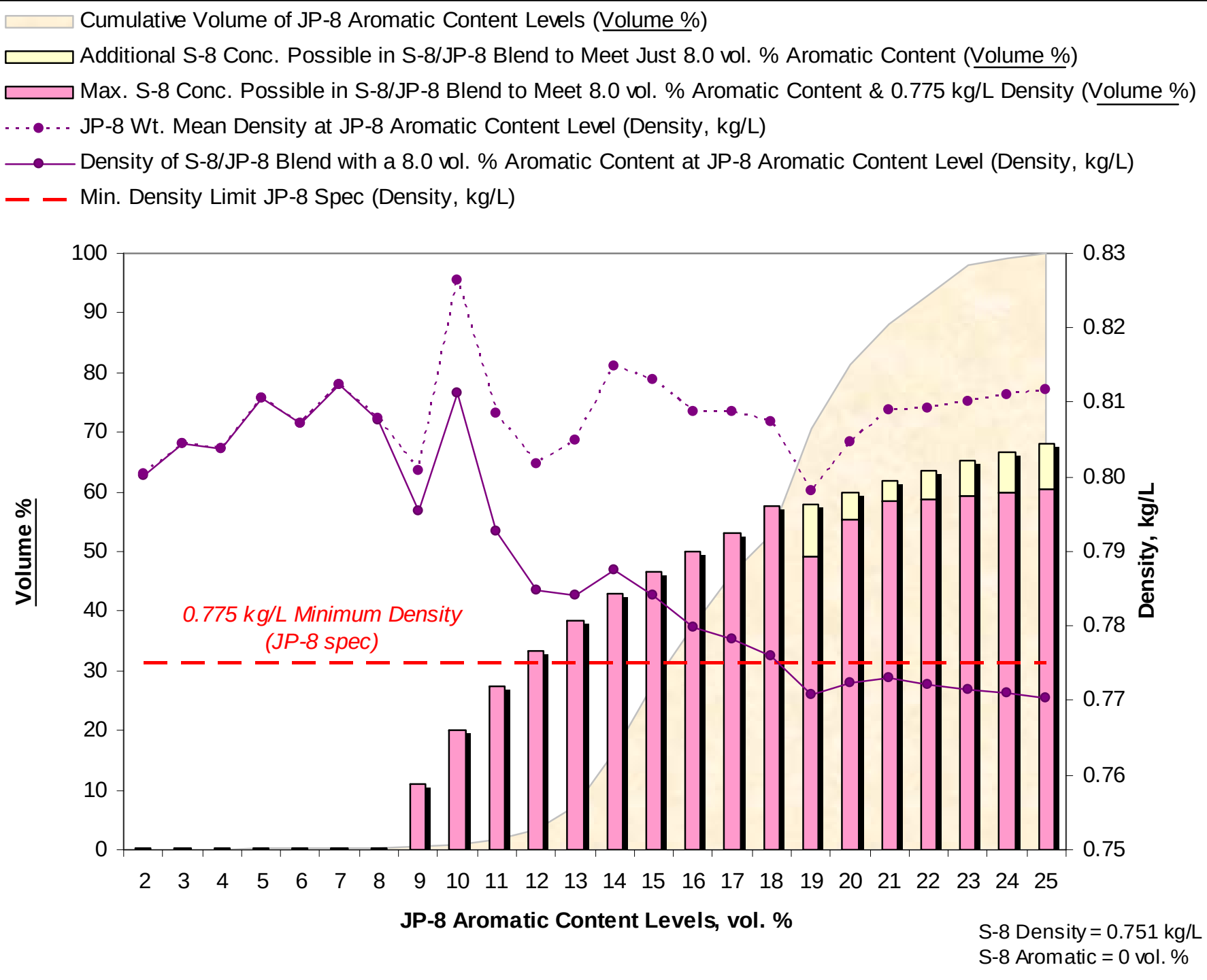
- For JP-8 2004 PQIS data ranging from 0.78 – 0.84 kg/L Density Levels it is possible to blend in FT IPK with density of 0.751 kg/L:
  - In concentrations ranging from 17.2% to as high as 73.0% by volume and still meet the JP-8 specification lower density of 0.775 kg/L
  - In concentrations ranging from 17.2% to as high as 56.0% by volume and meet both the JP-8 specification lower density of 0.775 kg/L and a minimum aromatic content of 8.0% vol.
- For JP-8 2004 PQIS data, on a weighted basis across all JP-8 Density Levels, it is possible to blend in FT IPK with density of 0.751 kg/L:
  - At a concentration of 55.1% by volume and still meet the JP-8 specification lower density of 0.775 kg/L
  - At a concentration of 50.4% by volume and still meet both the JP-8 specification lower density of 0.775 kg/L and a minimum aromatic content of 8.0% vol.

Calculating Properties of "Virtual" Blends Based on Meeting Minimum Density

- At JP-8 Density Level = 0.80 kg/L, a maximum S-8 concentration of of 51 vol. % is possible while still meeting JP-8 minimum specification density of 0.775 kg/L
- Blending in 51 vol. % of S-8 changes other fuel properties in addition to density:
  - Aromatic content is diluted from 17.1 to 8.4 vol. %
    - 17.1 vol. % aromatic content is the weighted mean aromatic content at the JP-8 Density Level = 0.80 kg/L
  - Sulfur content decreases from 0.036 to 0.018 mass %
  - Cetane index improves from 44.9 to 56.2

Creating “Virtual” Blends Based on Meeting Minimum Aromatic Content

- If the calculation is done based on reaching the minimum aromatic content at each Density Level, the maximum blend percentage of S-8 possible is different
- For example, the weighted mean aromatic content at the JP-8 Density Level = 0.80 kg/L is 17.1 vol. %
- Assuming the desired final blend aromatic content is 8.0 vol. % (to meet the minimum allowed per DEF STAN 91-91) then:
  - 53.2 vol. % S-8 can be blended into the fuel blend
  - Again, other properties of the blend change accordingly with the amount of S-8 blended


Cumulative Volume of JP-8 Aromatic Content Levels (Volume %)
Additional S-8 Conc. Possible in S-8/JP-8 Blend to Meet Just 8.0 vol. % Aromatic Content (Volume %)
Max. S-8 Conc. Possible in S-8/JP-8 Blend to Meet 8.0 vol. % Aromatic Content & 0.775 kg/L Density (Volume %)
JP-8 Wt. Mean Density at JP-8 Aromatic Content Level (Density, kg/L)
Density of S-8/JP-8 Blend with a 8.0 vol. % Aromatic Content at JP-8 Aromatic Content Level (Density, kg/L)
Min. Density Limit JP-8 Spec (Density, kg/L)
Volume %
Density, kg/L
0.775 kg/L Minimum Density
(JP-8 spec)
JP-8 Aromatic Content Levels, vol. %
S-8 Density = 0.751 kg/L
S-8 Aromatic = 0 vol. %

Key Takeaways from JP-8 Aromatic Level Slide

- For JP-8 2004 PQIS data ranging from 2 – 25% vol. Aromatic Levels it is possible to blend in FT IPK with density of 0.751 kg/L:
  - In concentrations ranging from 0% to as high as 68.0% by volume and still meet a minimum aromatic content of 8.0% vol.
  - In concentrations ranging from 0% to as high as 60.5% by volume and meet both a minimum aromatic content of 8.0% vol. and the JP-8 specification lower density of 0.775 kg/L and For JP-8 2004
- For JP-8 2004 PQIS data, on a weighted basis across all JP-8 Aromatic Levels, it is possible to blend in FT IPK with density of 0.751 kg/L:
  - At a concentration of 53.4% by volume and still meet a minimum aromatic content of 8.0% vol.
  - At a concentration of 50.5% by volume and still meet both a minimum aromatic content of 8.0% vol. and the JP-8 specification lower density of 0.775 kg/L

Properties of Real Blends

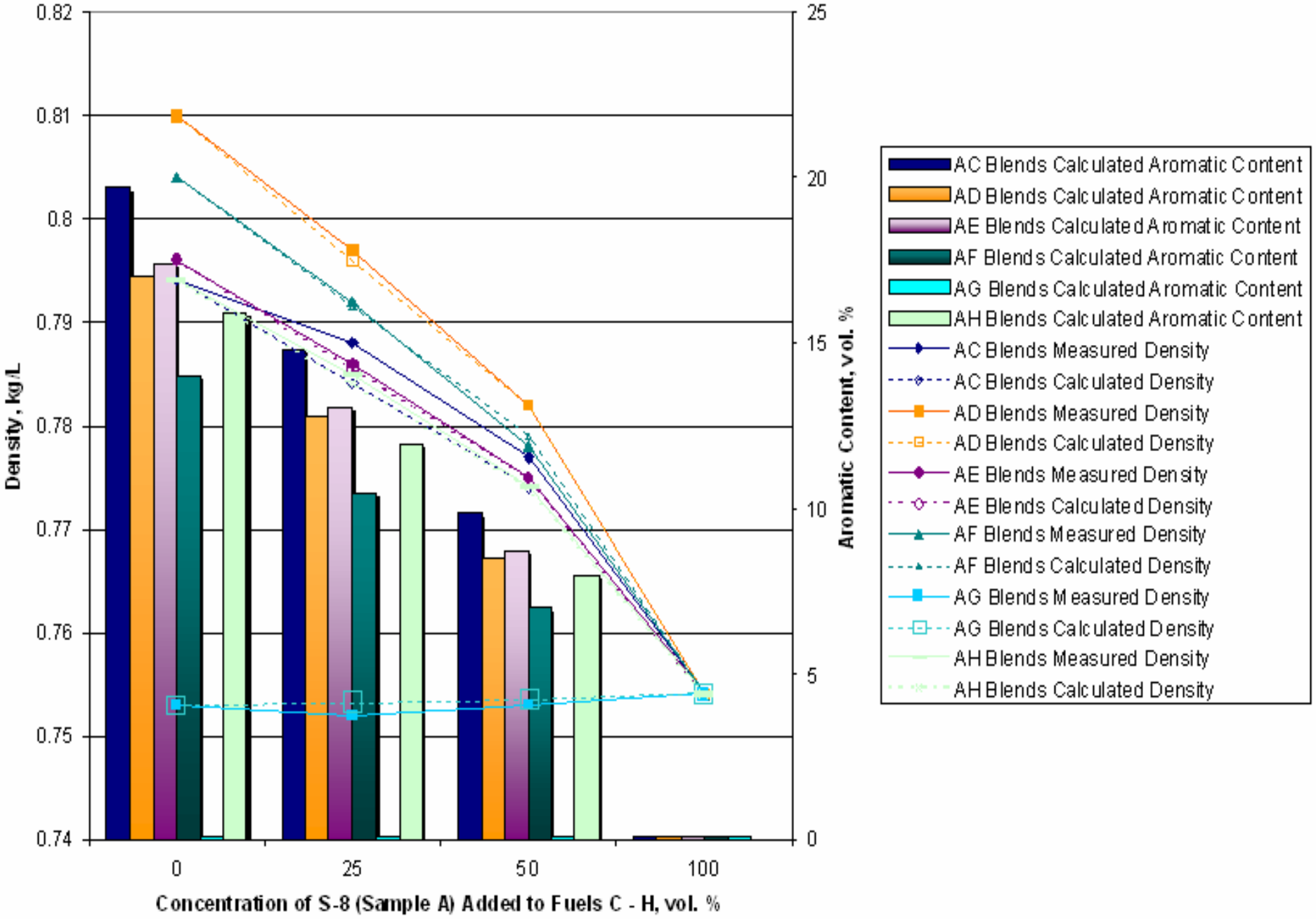
- Real S-8/JP-8 fuel blends were prepared and property tests were performed
- Five unidentified JP-8 fuels and one unidentified S-8 fuel (control sample) were blended with two S-8 fuels at 25 and 50 vol. % of S-8 each
- The five JP-8 fuels had densities ranging from 0.794 to 0.810 kg/L
  - About 78% of the JP-8 fuels in the PQIS database fall into this density range
- Their aromatic content ranged from 14.0 to 19.7 vol. %.
  - About 74% of the JP-8 in the PQIS database fall into this aromatic content range

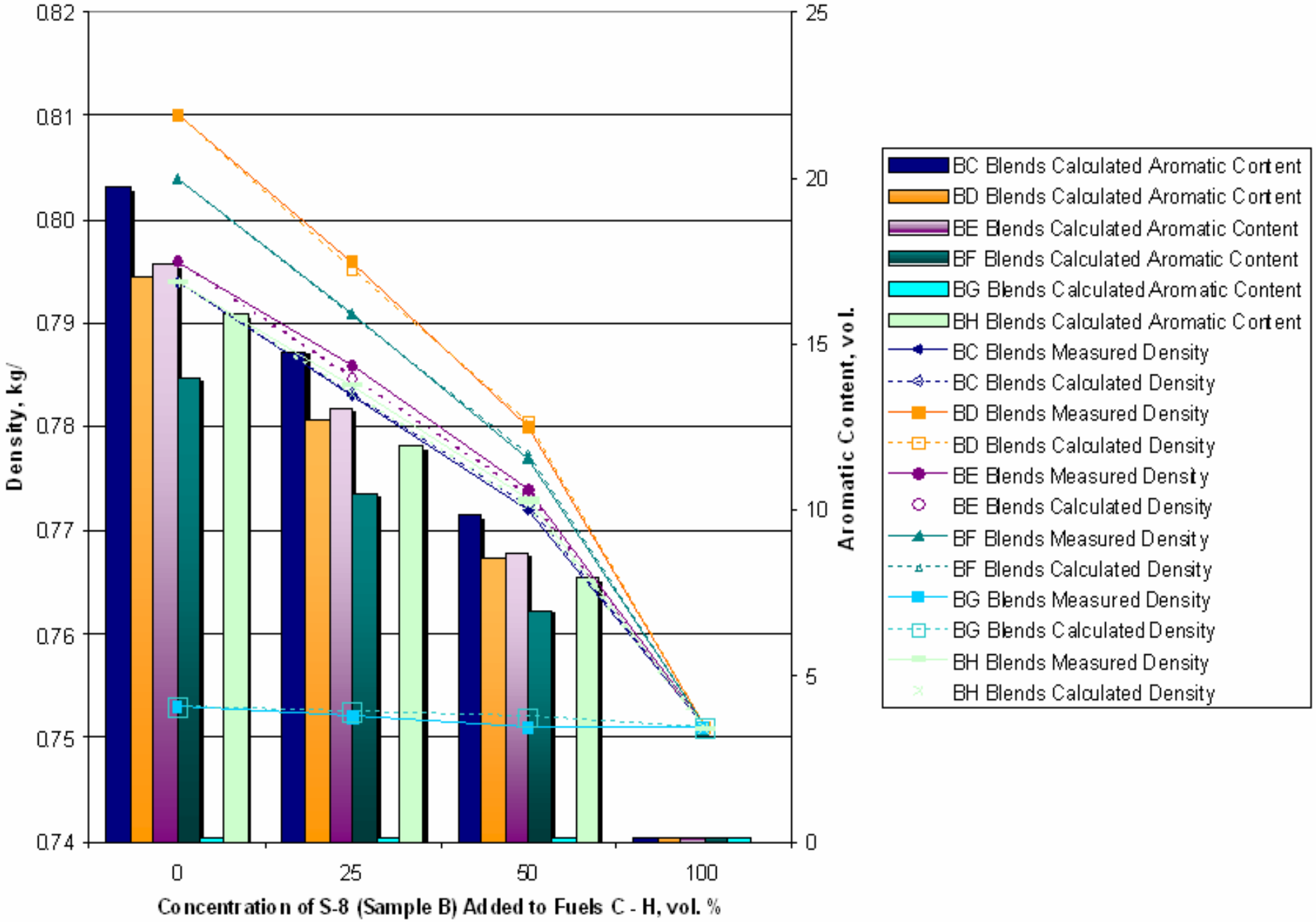
Properties of S-8 and JP-8

		S-8		JP-8					
Fuel Type		S-8	S-8	JP-8	JP-8	JP-8	JP-8	S-8	JP-8
Designation		A	B	C	D	E	F	G	H
Property, Units	Method								
Flash Pt., °C	D 93	54	48	48	51	48	53	---	---
Density, kg/L	D 4052	0.754	0.751	0.794	0.810	0.796	0.804	0.753	0.794
Aromatics, vol. %	D 1319	<1	<1	19.7	17.0	17.4	14.0	0.0	15.9
Sulfur, mass %	D 2622	<0.002	<0.002	0.08	0.14	0.08	0.12	0.00	0.07
Net Heat of Combustion				18604	18541	18594	---	18965	18625
Freeze Pt., °C	D 5972	-52	-57	-49	-57	-50	-44	-57	-50
Viscosity at 40°C	D 445	1.4	1.3	1.3	1.4	1.4	1.4	1.5	1.5
SimDist., °C	D 2887								
IBP		131	116	109	105	102	109	116	104
5%		143	139	149	147	143	151	139	142
50%		216	204	202	209	201	217	204	198
95%		282	280	259	261	266	272	279	265
FBP		332	316	282	303	289	301	310	288
Cetane Index	D 976	70	67	47	43	46	48	66	46

Properties of Real S-8/JP-8 Blends

- 20 of the 24 samples were S-8/JP-8 blends and four were S-8/S-8 blends
- When 25 vol. % of S-8 was added to the JP-8 samples:
  - None of the samples fell below the minimum density requirement
  - None fell below the minimum allowable aromatic content
- When 50 vol. % of S-8 was added to the JP-8 samples:
  - Five of the 20 fuels fell below the minimum density requirement (actually measured density; six fell below when density was mathematically predicted)
  - Two of the 20 fell below the minimum aromatic content requirement


0.82
0.81
0.8
0.79
0.78
0.77
0.76
0.75
0.74
Density, kg/L
25
20
15
10
5
0
Aromatic Content, vol. %
0
25
50
100
Concentration of S-8 (Sample A) Added to Fuels C - H, vol. %
AC Blends Calculated Aromatic Content
AD Blends Calculated Aromatic Content
AE Blends Calculated Aromatic Content
AF Blends Calculated Aromatic Content
AG Blends Calculated Aromatic Content
AH Blends Calculated Aromatic Content
AC Blends Measured Density
AC Blends Calculated Density
AD Blends Measured Density
AD Blends Calculated Density
AE Blends Measured Density
AE Blends Calculated Density
AF Blends Measured Density
AF Blends Calculated Density
AG Blends Measured Density
AG Blends Calculated Density
AH Blends Measured Density
AH Blends Calculated Density


0.82
0.81
0.80
0.79
0.78
0.77
0.76
0.75
0.74
Density, kg/
25
20
15
10
5
0
Aromatic Content, vol.
0
25
50
100
Concentration of S-8 (Sample B) Added to Fuels C - H, vol. %
BC Blends Calculated Aromatic Content
BD Blends Calculated Aromatic Content
BE Blends Calculated Aromatic Content
BF Blends Calculated Aromatic Content
BG Blends Calculated Aromatic Content
BH Blends Calculated Aromatic Content
BC Blends Measured Density
BC Blends Calculated Density
BD Blends Measured Density
BD Blends Calculated Density
BE Blends Measured Density
BE Blends Calculated Density
BF Blends Measured Density
BF Blends Calculated Density
BG Blends Measured Density
BG Blends Calculated Density
BH Blends Measured Density
BH Blends Calculated Density

Measured vs. Predicted Properties of Blends

- Predicted (calculated) properties, as expected, closely matched measured properties
  - Sulfur content was predicted for the real blends. Similar to aromatic content, the concentration of sulfur decreases as the concentration of S-8 (zero sulfur) is increased
  - Measured and predicted densities show a trend of lower blend density as the concentration of S-8 increased
    - Average standard deviation between densities measured by ASTM D 4052 and those mathematically predicted was 5.89e-4 kg/L
    - Standard deviation suggests mathematical prediction of densities is representative of real fuel blend densities

Conclusions

- This study examined and presented the “property box” of JP-8 fuel (CONUS) using the Defense Energy Support Center “Petroleum Quality Information System” (PQIS) database for JP-8 fuel procured during 2004
- Employed key criteria for creating blends of FT IPK and JP-8:
  - That meet the minimum acceptable density of 0.775 kg/L in the current JP-8 specification, and
  - That meet the minimum acceptable aromatic content of 8.0 vol. % as published in DEF STAN 91-91 Issue 5
  - To develop and present data for “virtual” blends of FT IPK and JP-8 (CONUS Defense Regions 1-5) and illustrating that significant volumes of FT IPK could be used in blends with JP-8 while still meeting the key blending criteria
    - On a macro-scale across all JP-8 volume (2004 PQIS data), it is possible to add 50.5% FT IPK (by volume) and still meet both 0.775 kg/L and minimum aromatic content of 8% vol.
    - Amounts of FT IPK possible in individual blend batches will vary widely based on actual properties of the specific JP-8 used for that batch
- Showed that mathematically predicted (calculated) properties closely matched measured properties for real blends of FT IPK and JP-8

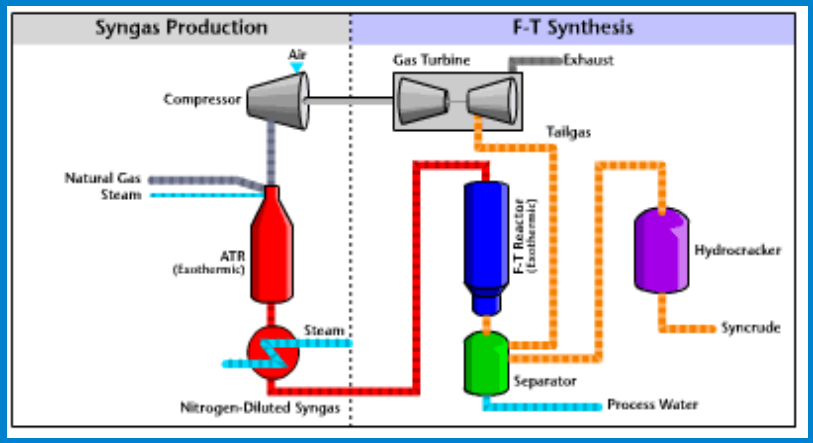
Recommended Follow-on Study

- Develop most likely scenarios for implementing near-term use of blends based on proximity of DoD bases to potential manufacturing sites of FT IPK
  - Obtain and analyze JP-8 samples from DoD bases identified in the most likely scenarios
- Obtain as possible and analyze JP-8 samples “of interest” based on analysis of 2004 PQIS data; e.g., there were batches of JP-8 with very low aromatic content (Region 3)
- Make blends of the JP-8 samples obtained with FT IPK and analyze to populate database of blend properties
- Analysis of JP-8 fuels and blends to include
  - Standard specification tests per ASTM D 1655
  - Kinematic Viscosity at 40°C, Cetane Index (of interest for diesel engines)
  - Kinematic Viscosity at low temperatures (other than just -20°C) to better understand low temperature characteristics and determine temperature at which viscosity = 12 cSt

Questions?

Fischer-Tropsch (FT) Fuel

- FT fuels can be produced domestically from a variety of non-petroleum feed stocks including:
  - Natural gas
  - Coal
  - Petroleum coke
  - Biomass and various wastes



Graphic representation of Syntroleum Corp. process, used with Syntroleum permission

- FT process:
  - Production of synthesis gas (syngas)
  - Process syngas to high-boiling hydrocarbons.
  - Hydrocarbons are then hydrocracked, hydroisomerized, and/or hydroprocessed to produce the desired liquid fuels

Joint Battlespace Use Fuel of the Future (JBUFF)

Single Battlefield Fuel

- JP-8/F-34
  - MIL-DTL-83133
- JP-5/F-44
  - MIL-DTL-5624
- Jet A-1/F-35
  - ASTM D 1655 (U.S.)
  - British Defence Standard [DEF STAN] 91-91 (British military, most of commercial aviation worldwide)

JBUFF

- JP-8/JP-5/Jet A-1 (petroleum)
- FT Iso-Paraffinic Kerosene (IPK)
- JP-8/FT IPK blends (petroleum/FT blend)

End-uses in DoD fleets